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CHAPTER II

Problems of Salinity in Agriculture

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A. Introduction

Millions of hectares of land throughout the world are too saline to produce economic crop yields, and more land becomes nonproductive each year because of salt accumulation. Salinity problems in agriculture are usually confined to arid and semiarid regions where rainfall is not sufficient to transport salts from the plant root zone. Such areas comprise 25% of the earth's surface (THORNE and PETERSON, 1954). Salinity is a hazard on about half of the irrigated area of the western USA (WADLEIGH, 1968) and crop production is limited by salinity on about 25% of this land (WADLEIGH, 1968; THORNE and PETERSON, 1954; BOWER and FIREMAN, 1957). The occurrence of salinity is similar in the arid regions of western Canada, the high plains of Mexico and the Pacific slopes of South America. Salt affected soils are also extensive in South Africa, Rhodesia, Egypt, Marocco, and Tunisia. Only small areas of salt affected soils occur in Europe, but extensive areas are present in Asia (THORNE and PETERSON, 1954). In general, it can be concluded that salinity problems are found in all countries having areas where arid or semiarid climates exist.

Soil salinity problems are present in nearly every irrigated area of the world and also occur on non-irrigated croplands and rangelands. CARTER et al. (1964) reported that approximately 25% of the non-irrigated land in the Lower Rio Grande Valley of Texas is highly saline. The saline soils are interspersed among non-saline soils so that farmers must plant and cultivate saline areas along with non-saline areas. Thus, farmers may actually harvest only about 75% of the land area they farm. Similar problems face farmers throughout the world, adding to operational costs and making farming less practical.

The actual total area of salt affected soils throughout the world is not known, but it is large. A recent survey indicated that the irrigated areas of 103 countries totaled 203 million hectares (ANONYMOUS, 1970). If 25% of this land is saline, then there are 50 million hectares of irrigated, salt affected soils. In addition, there are large areas of non-irrigated salt affected soils. Therefore, the salinity problem in agriculture is extensive and important.

The importance of the salinity problem varies among countries. AYERS et al. (1960) reported that salt affected soils of Spain constitute only a small percentage of the total arable lands, but they estimated that 250000 hectares are affected to the extent that crop yields are depressed. In contrast, the 17 Western States in the USA have a total of approximately 8 million acres of salt affected soils (BOWER and FIREMAN, 1957). It is not the purpose of this chapter to discuss salt affected soils of each nation, but rather to discuss the nature of the salinity problems in agriculture, and to some extent, what can be done about these problems. A useful bibliography of papers published on salt affected soils and their management is available (CARTER, 1966).

Salt affected lands can usually be made productive by reclamation and better management if resources are available, but reclamation cost greatly increases production costs. In many cases, projected reclamation costs far exceed expected returns from the land, and reclamation is not practical. In other cases resources, such as water for leaching and good quality water for irrigation, are not available, and reclamation cannot be accomplished.

B. Causes of Salinity

Water evaporates in a pure state, leaving salts and other substances behind. As water is removed from the soil by evapotranspiration (ET), the salt concentration in the remaining soil solution may become 4–10 times that in the irrigation water within 3–7 days after irrigation (PETERSON et al., 1970). Each irrigation adds some salt to the soil. How much is added depends upon the amount of water entering the soil and the salt concentration in the water. This salt remains in the soil and accumulates unless it is leached away by water applied in excess of crop requirements. The trend of salt accumulation in soil irrigated with waters having four different salt concentrations is illustrated in Fig. 1. It is assumed that there is no leaching and that each irrigation replaces exactly the water removed from the soil by ET. As illustrated by Fig. 1, numerous irrigations with water of low salt content, can be applied before the tolerance limit for a crop is reached, but the crop tolerance level is reached rapidly when irrigating with water of high salt content. Sufficient leaching to remove the salt brought into the soil by each irrigation will

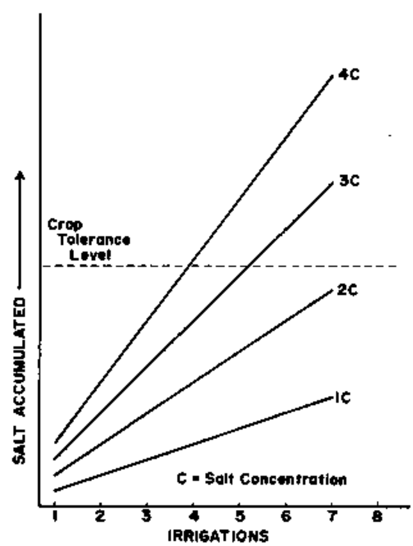


Fig. 1. Hypothetical salt accumulation in soil as related to the salt concentration in irrigation water and number of irrigations, in the absence of leaching

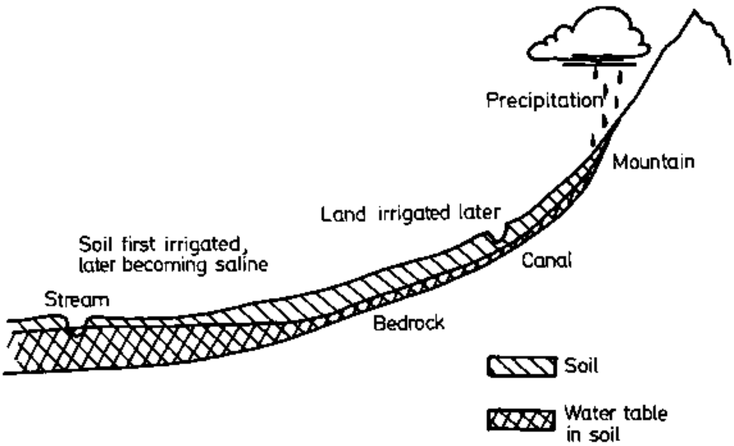


Fig. 2. Formation of salinity and high water table problems in fertile lowlands as a result of excessive irrigation at higher elevations

keep the amount of salt in the soil at the same level as it was after the first irrigation. Less leaching would not prevent salt accumulation, but would increase the number of irrigations that could be applied before the salt tolerance limit for the crop is reached. Figure 1 is a generalized illustration. It should be realized that the tolerance level varies for different crops.

Drainage water that has passed through the soil has a higher salt concentration than the irrigation water (WILCOX and RESCH, 1963; CARTER et al., 1971). Most of this drainage water returns to the natural stream or river channel, downstream from the point where the irrigation water is diverted. As a result, the salt concentration in rivers and streams in arid and semiarid regions generally increases from the headwaters to the mouth. This, in itself, creates a salinity problem for agriculture, because the salt concentration in the stream can become so high that the water cannot be used for irrigation.

Irrigating one area may cause salt problems in another. Salts may be transported from one cropped area with adequate drainage to another with inadequate drainage where they accumulate. In many irrigated valleys, this problem has seriously limited productivity on the best agricultural soils. Usually, lands adjacent to the river or stream were the first to be irrigated. Later, water distribution systems were developed to irrigate lands at a higher elevation. If too much water was applied on these higher elevation lands, drainage water from these lands caused high water tables and salt problems on those lower lands first irrigated. In many valleys, this process has caused the lands next to the river or stream to become saline marshes, useful only for wildlife and waterfowl habitat. Examples of these processes are evident in most irrigated valleys of the western U.S. Natural precipitation has caused the same problem in some areas. The situation is illustrated in Fig. 2. In some cases, artificial drainage in the low land and better water management on the entire area can return the soils adjacent to the stream to good productivity.

Although salt accumulation resulting from ET is the primary cause of salinity problems in agriculture, there are other sources of salt. Some soils naturally contain sufficient salt to limit or prohibit production of economic crops. Some of these soils were derived from saline parent materials, and some contain natural salt deposits. Old lakebed soils, for example, often contain salt deposits. Some soils have received sufficient salt from sea spray to become saline or contain naturally high salt levels (YAALON, 1963). Another salt source is the soil. As water from precipitation or irrigation passes through the soil, natural salt-bearing minerals are very slowly dissolved. As the dissolved salts are transported away by water, the equilibrium between the solid and dissolved phases shifts and more salts are dissolved. Salts from this source are transported to an area where the water is evaporating and the salts are concentrated. Although salts dissolve slowly from most soil minerals, 2.2 metric tons or more per hectare can be dissolved in a year from some calcareous silt loam soils (CARTER et al., 1971).

Ancient natural salt deposits in the soil, usually referred to as fossil salts, are found throughout arid and semiarid regions. Saline materials also underlie some soils such as the Mancos Shale in Colorado (SKOGERBOE and WALKER, 1972). Water that comes in contact with these salts becomes highly saline. If this saline water reaches a surface stream or a groundwater acquifer being used for irrigation, severe salt accumulations can result that seriously limit crop production. There are also numerous natural saline groundwater acquifers. When water is pumped from these for irrigation, salts are brought to the surface where they accumulate and damage crops. As the demand for water increases, the tendency to develop groundwater sources also increases. This results in using more medium and high-salt groundwaters, thus intensifying the salinity problem.

Phreatophytes growing along canals and drains create an especially serious problem in water-short areas. These plants use water that may be needed for irrigation, leaving the salt behind so that the salt concentration in the remaining water is increased and the quality of the water is impaired for irrigation. Phreatophytes are found along most open, unlined canals and drains of irrigated areas. Seepage from canals also frequently causes high water tables, increases soil salinization, and encourages growth of the non-economic plants. Lining canals or installing pipelines can reduce these kinds of problems, but such practices are costly.

In summary, salinity problems in agriculture arise from many sources, both natural and man-caused. Salts are transported by water, and become problems when and where the water evaporates. Water evaporation from the soil leaves salts at or near the soil surface. Water evaporation through plants leaves salts near the point of water absorption by plant roots.

C. Coping with Salinity Problems

I. Crop Selection

Plants species differ in their tolerance to total salts and to specific ions. Also, crops that may be highly tolerant at one growth stage may be sensitive during another stage. Generally, plants are most sensitive to salinity during germination or early

Table 1. The EC_e at which 10, 25, and 50% yield reductions can be expected for various agricultural crops. (Adapted from BERNSTEIN, 1964)

	Percent yield reduction		
	10	25	50
Field Crops			
Barley	11.9	15.8	17.5
Sugarbeets	10.0	13.0	16.0
Cotton	9.9	11.9	16.0
Safflower	7.0	11.0	14.0
Wheat	7.1	10.0	14.0
Sorghum	5.9	9.0	11.9
Soybean	5.2	6.9	9.0
Sesbania	3.8	5.7	9.0
Rice	5.1	5.9	8.0
Corn	5.1	5.9	7.0
Broadbean	3.1	4.2	6.2
Flax	2.9	4.2	6.2
Beans	1.1	2.1	3.0
Vegetable Crops			
Beets	8.0	9.7	11.7
Spinach	5.7	6.9	8.0
Tomato	4.0	6.6	8.0
Broccoli	4.0	5.9	8.0
Cabbage	2.5	4.0	7.0
Potato	2.5	4.0	6.0
Corn	2.5	4.0	6.0
Sweetpotato	2.5	3.7	6.0
Lettuce	2.0	3.0	4.8
Bellpepper	2.0	3.0	4.8
Onion	2.0	3.4	4.0
Carrot	1.3	2.5	4.2
Beans	1.3	2.0	3.2
Forage Crops			
Bermudagrass	13.0	15.9	18.1
Tall wheatgrass	10.9	15.1	18.1
Crested wheatgrass	5.9	11.0	18.1
Tall fescue	6.8	10.4	14.7
Barley hay	8.2	11.0	13.5
Perennial rye	7.9	10.0	13.0
Hardinggrass	7.9	10.0	13.0
Birdsfoot trefoil	5.9	8.1	10.0
Beardless wildrye	3.9	7.0	10.8
Alfalfa	3.0	4.9	8.2
Orchardgrass	2.7	4.6	8.1
Meadow foxtail	2.1	5.5	6.4
Clovers, alsike and red	2.1	2.5	4.2

seedling growth. Some crops, such as rice, are also sensitive during flowering and seed set (PEARSON et al., 1966). Well-established plants are usually more tolerant than new transplants (BERNSTEIN, 1964). Therefore, crop selection is an important management decision in salinity affected areas. Severe salinity problems may preclude growing salt sensitive crops and may require special practices to produce economic yields of salt tolerant crops. Mild salinity problems may require special practices only for crop establishment.

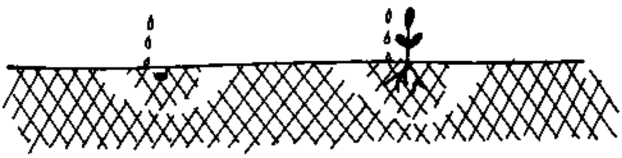
The United States Salinity Laboratory Staff has conducted extensive research on the salt tolerance of agricultural plant species, and combined their results with those of other researchers throughout the world to compile salt tolerance listings for different plant species (U.S. Salinity Laboratory Staff, 1954; BERNSTEIN, 1964). In these listings the tolerable level of salinity is based on the electrical conductivity of saturated soil extracts for which the symbol is EC_e and the units are millimhos per centimeter (mmhos/cm). The EC_e is related to the number of electrical conducting ions in solution, and an EC_e of 1.0 corresponds to a total salt concentration of approximately 640 parts per million. The salt concentration in the soil solution at field capacity will be twice that in the saturated extract. A listing of salt tolerance values adapted from data reported by BERNSTEIN (1964) for field, vegetable and forage crops is presented in Table 1. These data are based on EC_e measurements made on the saturated soil extracts during the period of rapid plant growth and maturation, from late seedling stage onward. Some plants are sensitive to specific ions such as boron (WILCOX, 1960), chloride, and sodium (BERNSTEIN, 1964), but this will not be dicussed in this chapter.

II. Crop Stand Establishment

Because many plant species are most sensitive to salinity during germination or early seedling development, several cultural and management practices have been developed to enhance stand establishment. One practice is to irrigate lightly each day after seeding with a solid set sprinkler system until the stand is established and then convert to furrow or less frequent sprinkler irrigation. Another technique is to leach salts from surface soils just before planting to allow stand establishment before salts can accumulate enough to interfere with germination or to damage seedlings. This approach is not always successful because if evaporative demand is high, water moves rapidly to the soil surface, evaporates, and leaves salt behind. A third cultural practice is to bed the area to be seeded so that salts accumulate at the ridge tops, and then seed on the slope between the furrow bottom and ridge top (Fig. 3) (BERNSTEIN and FIREMAN, 1957; BERNSTEIN, 1964). This can be done with double row or single row seeding. Trickle irrigation is a new practice that appears to have some merit for establishing stands and for growing the crop to maturity (BERNSTEIN and FRANCOIS, 1973; GOLDBERG et al., 1971; GOLDBERG et al., 1971). This practice keeps a zone low in salt around the plant roots or seed.

Fortunately, in many areas, precipitation between cropping seasons is sufficient to leach salts from surface soils and to allow crop stand establishment before salts accumulate again to harmful concentrations. In such areas, evaporation between crop seasons is usually low, and the precipitation effectively leaches salts downward in the soil without much upward return to the soil surface. Leaching by natural precipitation will be most effective if the soil water content is high when the precipitation occurs, so that the water from precipitation will not all be

Salts are moved to the ridge tops and accumulate there as water evaporates. Seed placed in the salt accumulation zones may not germinate or seedlings may die because of salt effects. Seed placed along the slope is less likely to be affected by salt accumulations. This method can be used with both single and double row systems.



Drip irrigation maintains a low salinity zone around the seed and allows germination and plant establishment.

Salt accumulations

Fig. 3. Bedding soil so that salts accumulate at the high point. Seeding on the sloping soil between the water line in the furrow and the high point allows stand establishment. Drip irrigation moves salt away from the seed and root zone

used for filling the soil root zone, but will force water from it. Although it is not widely practiced, leaching during a cool noncropping season, when evaporation is low, is very effective if good quality water is available. In some areas the noncropping season is during the warmest and driest time of the year. Under such conditions, the approach described above is not usually beneficial.

Several other practices have been used to enhance seedling establishment and increase production. CARTER and FANNING (1965) applied a cotton bur mulch to reduce evaporation and enhance leaching, and then seeded grain sorghum through the mulch. A satisfactory crop was produced by this method. These investigators had shown earlier that cotton bur and wood chip mulches effectively reduced evaporation, increased water intake, and increased leaching of salts (FANNING and CARTER, 1963; CARTER and FANNING, 1964). RASMUSSEN et al. (1972) have demonstrated that deep plowing of some salt affected soils brings about a complete reclamation. The success of deep plowing depends upon the texture and lime or gypsum content of the subsoil. High clay content in the subsoil limits the success of this practice.

III. Leaching Requirements

The excess water applied periodically to leach salts from the root zone is known as the leaching requirement (U.S. Salinity Laboratory Staff, 1954; WILCOX and RESCH, 1963; THORNE and PETERSON, 1954). Where soils are only slightly saline and the electrical conductivity of the irrigation water (EC_e) is below about 0.85 mmhos/cm, normal irrigation practices usually provide for sufficient leaching. What really happens is that the inefficiency of the irrigation practice provides sufficient excess water to meet the leaching requirement. Improving the irrigation efficiency increases the importance of taking into account the leaching requirement. If salt has accumulated in the root zone to near the tolerance level for the more tolerant plants, or if the irrigation water has an EC_e of 1.5 mmhos/cm or greater, leaching requirements are large and normal supplies of irrigation water may be insufficient to meet them. The specific effects of sodium on the structure and properties of the soil should also be considered when leaching.

IV. Drainage

Adequate drainage is essential for salinity control. The buildup of the groundwater table with subsequent movement of water to the soil surface to meet evaporative demands is a primary cause of soil salinity. Salinity resulting from high water tables can often be prevented or eliminated by applying less water or by proper drainage. Artificial drainage is costly, however, and drainage requirements and attendant costs should be carefully considered before a new area is brought under irrigation.

D. The Salt Balance Concept

The salt balance for any given land area or soil unit can be expressed by the following equation:

$$\mathrm{Sp} + \mathrm{Si} + \mathrm{Sr} + \mathrm{Sd} + \mathrm{Sf} = \mathrm{Sdw} + \mathrm{Sc} + \mathrm{Sppt}.$$

Where:

Sp = salt in natural precipitation falling upon the area,
Si = salt in the irrigation water diverted into the area,
Sr = residual salts in the soil,
Sd = salt dissolved into solution from soil minerals,
Sf = salt in applied fertilizers,
Sdw = salt in the drainage water from the area,
Sc = salt taken up by the crop and removed,
Sppt = salt chemically precipitated in the soil.

The salt in natural precipitation, Sp, is usually extremely small and can be ignored. In some areas, however, occasional storms do deposit sufficient salt to cause problems; for example, when strong winds have brought ocean spray inland or when dusts from salt flats have become airborne and then precipitate elsewhere. Si depends upon the salt concentration in the irrigation water, and the amount of water diverted into the area. Si is large for saline waters, and in many instances, it is the most important salt input factor. Sr, in some instances, is a large quantity such as found in arid land not previously irrigated, or where fossil salt deposits occur, but in soils used in agriculture the value of Sr is usually small. Sd varies with the kinds of minerals in the soil, and depends upon the amount of water passing through the soil and the salt concentration in that water. Sf is usually small and can generally be ignored. Sdw is usually a large output component particularly where irrigation waters are of poor quality and leaching is required. It may also be large for new lands brought under irrigation. Sc can be ignored in most irrigated areas because it is small in relation to other components. Sppt is a very important and complicated factor that is often not adequately evaluated. Under most irrigation practices, Sppt is small because excess water passing through the soil does not allow the salt concentration to become high enough for precipitation to occur. Ideally, Sppt should be maximized so that slightly soluble salts such as calcium carbonate and calcium sulfate will precipitate and remain in the soil. These salts when precipitated in the soil have little or no effect upon growing crops.

The salt concentration in the soil solution in the plant root zone is of primary importance. It increases between irrigations, as water is removed by evapotranspiration. Adding irrigation water decreases the salt concentration by dilution. The magnitude of the decrease depends upon the salt concentration in the irrigation water. If the salt concentration in the irrigation water is high–for example, above 1.5 mmhos/cm–the dilution will be slight, and more frequent irrigations will be required to maintain the salt concentration in the root zone below the level that would adversely affect plant growth and production. The application of more irrigation water adds more salt to the soil, requiring a greater leaching fraction to maintain a salt balance and avoid salt accumulation in the root zone.

Ideally, a salt balance should be maintained on all irrigated lands, once the salt concentration in the root zone has been reduced to the practical level that has the least adverse affects on plant growth and production. Maintaining a salt balance would maximize chemical precipitation of harmless salts; a minimum quantity of salt would be dissolved from soil minerals, and a minimum quantity of salt would be returned to river systems in drainage water. However, two important factors must be considered before water management practices are changed to maintain a salt balance: (1) the salinity tolerance of the crops grown governs the salt concentration permissible in the soil solution, below which the salt balance must be established for successful cropping, and (2) the salt concentration in drainage water will be likely to increase as irrigation practices are changed to effect a salt balance. The use of these drainage waters may be important, and increasing their salt concentration may render them unsatisfactory for that use. A third factor to consider in some areas is the disposal of animal, food processing and industrial waste effluents on the land. Some of these effluents contain large quantities of salt that will certainly have a significant impact upon the salt balance of an area.

E. Irrigation Return Flows

The increasing salt concentration in surface and groundwaters from irrigation return flows and drainage waters, is one of the most important salinity problems in agriculture. If one-half of the water applied for irrigation is used in evapotranspiration, the salt concentration in the drainage water will be twice that in the irrigation water, assuming that no salts are dissolved from or precipitated in the soil. Increasing the quantity of irrigation water applied would be likely to decrease the salt concentration in the return flows by dilution, but would probably increase the total salt loading from them by increasing Sd in the salt balance equation. Decreasing the amount of irrigation water may increase the salt concentration in the drainage waters, but it may decrease the salt loading by decreasing Sd and increasing Sppt. More research is needed to determine the influence of the amount of water applied on the Sd and Sppt factors in the salt balance equation.

Irrigating additional lands may increase the salt load in surface streams. This depends upon the type of irrigation used. Sprinkler, mist and trickle irrigation may not cause much return flow, but the salt left behind by the water used in evapotranspiration must go somewhere. Sometimes it is stored in the soil below the root zone. In some soils, tremendous quantities of salts can be stored between the bottom of the root zone and the groundwater for many years. A very efficient irrigation practice that will move water and salt downward primarily by unsaturated flow is required to accomplish this. However, the storage capacity may ultimately be filled, and then large quantities of salt can be expected in effluents for many years causing salinity problems to the future generations.

F. Conclusions

Excessive salt accumulations prevent or limit the production of economic crops on millions of hectares. These are primarily irrigated lands in arid and semiarid regions. Reducing the salt accumulations requires special management practices, which increase production costs. Excessive salt accumulations result primarily from water being removed in evapotranspiration, leaving salts behind to concentrate in the remaining water. Leaching to remove these accumulations impairs the quality of surface and groundwater in these areas, by increasing the salt concentration of the drainage waters. Each year more is understood about managing salt affected soils, but the problems are far from being solved and the need continues for new knowledge that may lead to more effective solutions of the salinity problems in agriculture.

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